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COMPARATIVE STUDY OF PYROLYSIS AND BIOGAS METHODS IN CATTLE MANURE PROCESSING

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There is about 1.5 billion cattle population on the earth. Each year, these ruminants are producing a huge amount of methane discharge to the atmosphere, some 10% of the total anthropogenic emission caused by fossil fuel combustion. A substance with a greenhouse effect 28 times higher than that of carbon dioxide, methane can remain in the atmosphere as long as 10 years.

A mature cow is producing 30 to 50 kg of manure per day. The average value of global daily production of manure is 60 million tons. This equals to ca 1,000,000 railroad cars. Each year, the 1.5 billion cattle population is averagely producing 21,600x10^6 tons of manure.

To comprehend the problem, compare the amount of manure being produced with the world coal production output. The 2019 output of ten coal production leader countries was 7,212x10^6 tons, three times less than the manure production value.

Manure is used as fertilizer to enhance the soil fertility as well as basic slurry component at biogas plants working with bovine manure.

In less developed countries, cattle manure is used as building material or hard stove fuel.

Regretfully, as the amount of processed manure is very small, this problem is among the most important ones in the list of problems that hamper the development of animal farming and adversely affect the global environmental situation.

Are there technologies in the world allowing the power-saving, commercially advantageous and environmentally friendly processing of such a tremendous amount of manure?

As far as I know, I may suppose that such technologies did not exist... until now.

Today, one of the mainstream approaches to bovine manure treatment is represented by biogas plants intended for animal farming and food industry waste disposal.

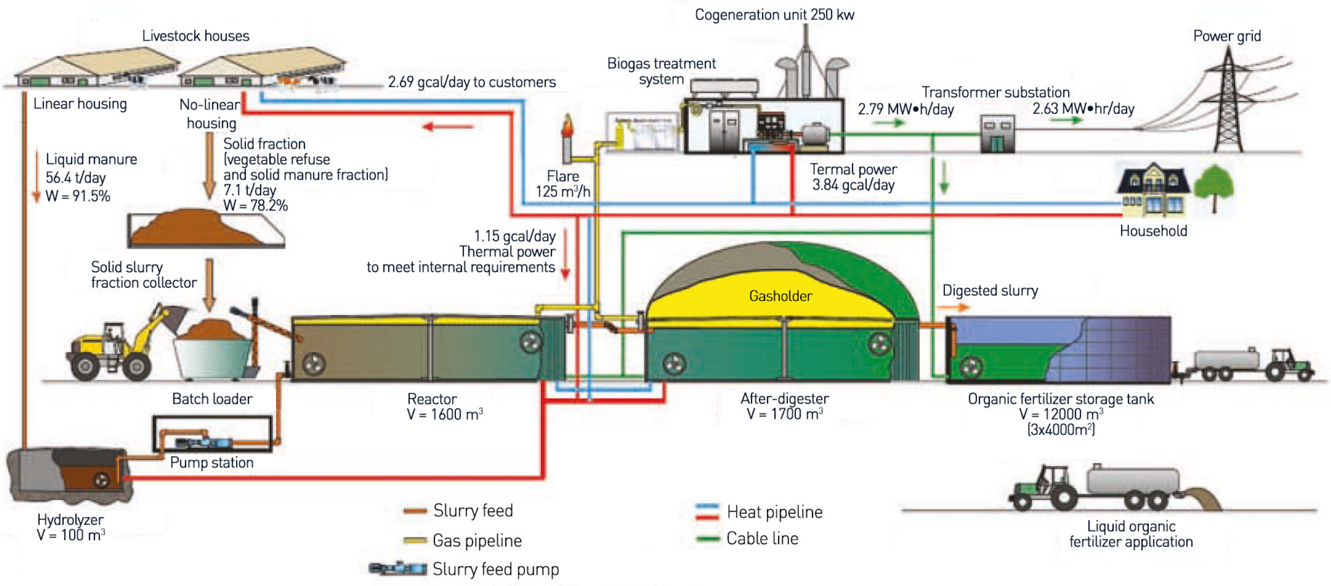

Fig.1. Biogas plant flow chart

Gas engine power plants are used for burning gas in the engines to generate electric power and obtain heat. Fed to the mains through an individual meter, the electric power is paid for by the government at a special high rate. Generally, this is the main source of biogas plant revenues. Electric power supply of all units and modules of the plant is provided from the state-owned networks at a standard rate. Biogas plant operation without governmental support proves to be commercially unreasonable.

Selling the liquid fertilizer product to neighboring farms can be the second source of biogas plant income. The problem here is that 40% of slurry cannot be fully digested by bacteria. Moreover, the mesophilic process temperature conditions (+37...+ 40°C) do not promote destruction of basic pathogenic germs. This factor poses a hindrance for certification of the processed slurry as a fertilizer with state agencies. The certification process takes about three years.

Consider the composition of the biogas product. It may be divided into two parts: energetic and ballast.

The energetic part is composed of methane (CH_4) accounting for ca 60% of the total volume. The ballast part includes several gases:

- Basic component, up to 38 % — carbon dioxide (CO_2); non-combustible;
- Hydrogen sulfide (H_2S), though combustible, is recommended for removal from the gas mixture, because of its strong adverse impact on the gas engine plants and environment;
- Ammonia (NH_3) is also a combustible gas. However, its inflammation temperature is high enough to have a detrimental effect on copper parts of the engines. The percentage of this gas is insignificant.

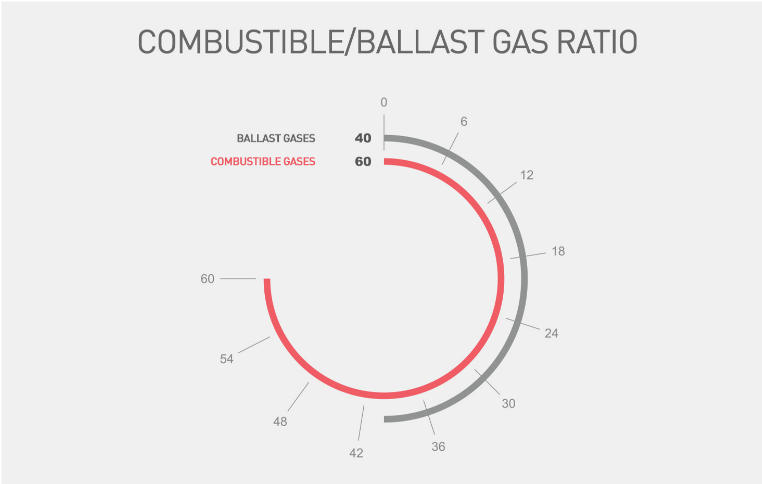

Fig.2. Combustible-to-ballast gas ratio for a biogas plant.

Since the calorific efficiency of the gas produced by biogas plants is quite low: ca 22.0 MJ/m^3, its amount required for generation of 1.0 kW electric power would be much higher than that of natural gas (0.36 to 0.38 m^3 per 1.0 kW/h electric power.

It should be noted, in particular, that specific capital costs per 1.0 kW/h of plant capacity vary in a range of 3000 to 5000 euros net of installation and commissioning. The biogas plant payback period is 5 to 13 years.

So, what is the purpose of adopting low-efficiency and expensive biogas plants?

The only reason is to somehow diminish the adverse impact of manure output on the environment. Otherwise, the farmlands, rivers and lakes would perish, air be filled with fetid vapors and human civilization sink in sewage.

How can we solve this problem in a power-efficient, clean and commercially advantageous way? Is it possible to transform manure from a problem into a sustainable source of energy and income for the mankind?

We present in this paper a new technical solution of the above problem that has been proposed by our R&D engineering team.

It may seem a commonplace but this is the high-temperature pyrolysis of specially treated high-humidity fresh manure. Unlike conventional methods, our technology does not suppose the drying of manure associated with high losses of gas dissolved in liquid manure.
As an example, consider a containerized pyrolysis plant for manure processing with a capacity of 30 tons per day.

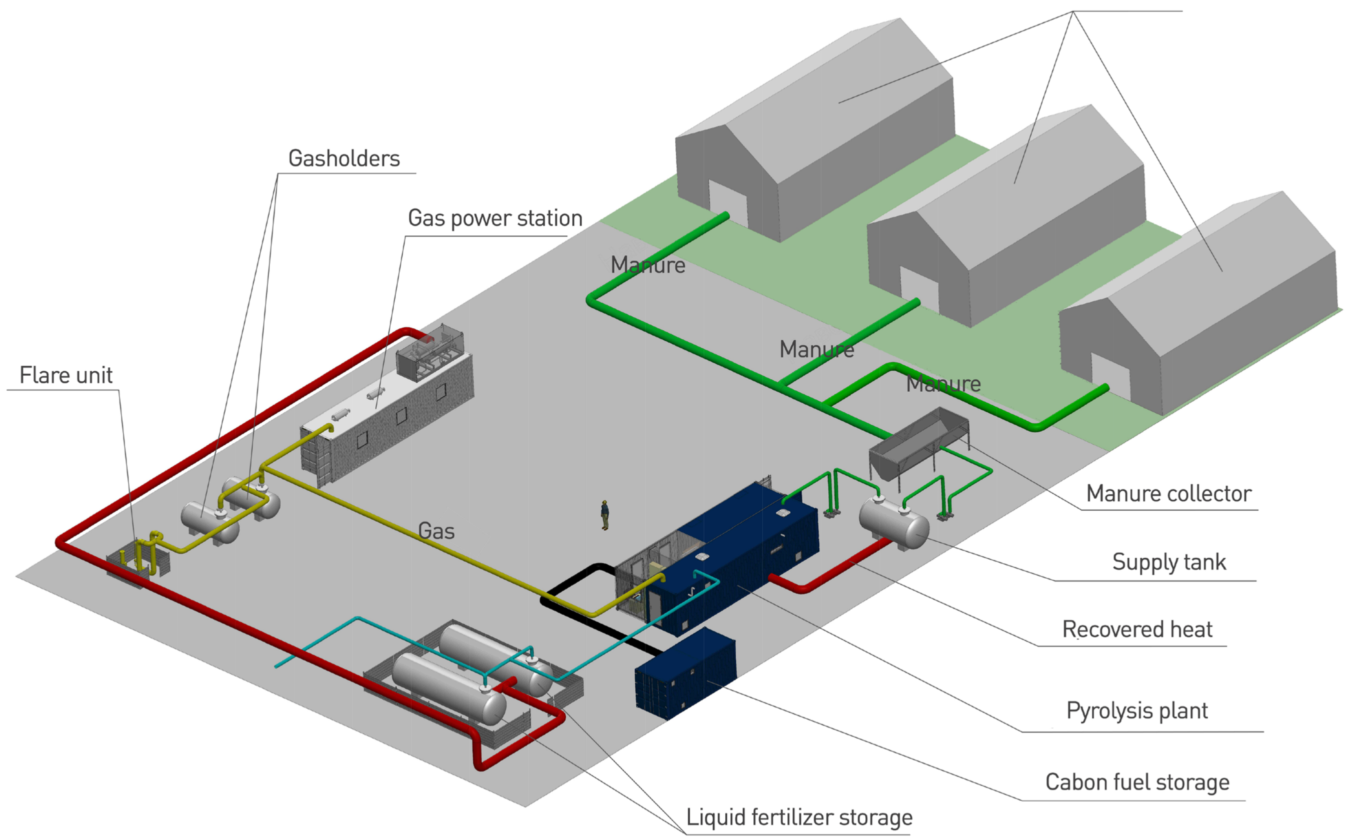

Fig.3. Pyrolysis plant layout diagram.

Manure is fed from the cowsheds to the separation module for separation of excessive water. Partially dewatered, manure passes to the collector for accumulation. It is fed from there to the intermediate supply tank equipped with a heating and stirring system. Then, the treated manure passes to the continuous-flow pyrolysis reactor for decomposition at a temperature of 1000^{0}C into 3 basic components: gas, pyrolysis water and carbon residue.

According to our method, the pyrolysis gas after complete (100%) purification is fed to the gasholders and further to gas engine power plant. Subject to technological requirements, the gas may be burned in a clean manner at the flare unit.

Similar to biogas, the pyrolysis gas may be divided into two components: energetic and ballast.

The energetic part is composed of a mixture of methane and other high-BTU hydrocarbon gases accounting for 87% and more in the total volume. The ballast component is quite small, not beyond 10-12%.

Gas obtained using the manure pyrolysis process has a high calorific value of 43.14 MJ/m3 (comparable with that of natural gas).

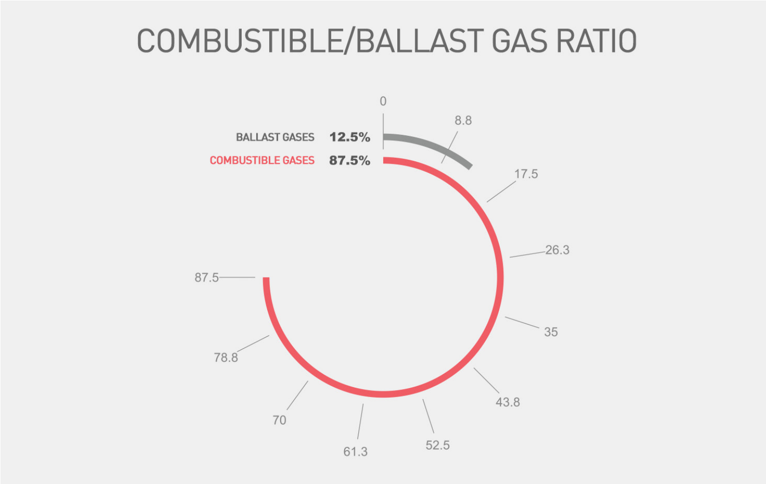

Fig.4. Combustible-to-ballast gas ratio for a pyrolysis plant.

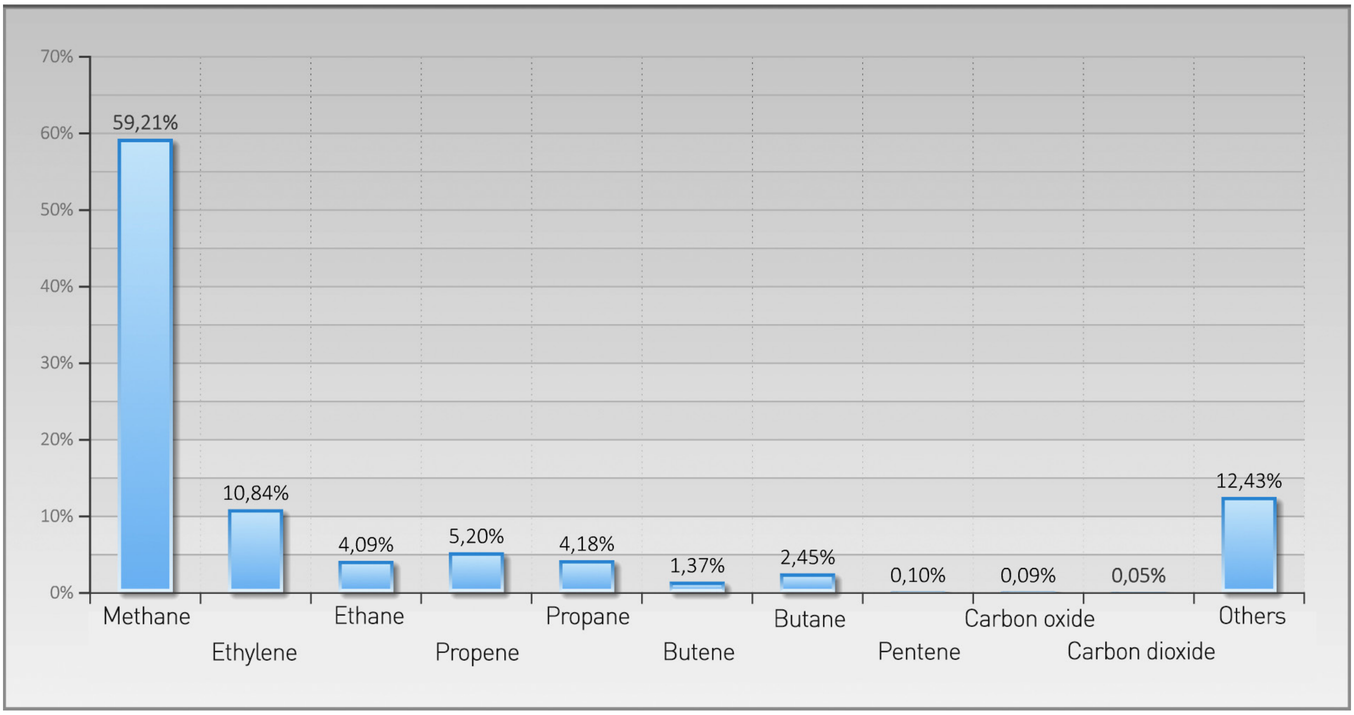

Fig.5. Pyrolysis gas content.

Water containing dissolved organic and nonorganic matter, a liquid product of manure pyrolysis, passes to the liquid fertilizer storage and further to the customers. According to chemical assay, such water contains nitrogen compounds, minerals and inorganic salts.

№	Description	Actual value
1	Density at 20^{0}C, g/cm^3	1,0
2	pH factor	4,8
3	Suspended solids, mg/dm^3	700
4	Ammonium nitrogen, mg/dm^3	221,7
5	Chloride ion, mg/dm^3	386,0
6	Sulfate ion, mg/dm^3	9,1
7	Mineralization, g/l Inorganic salt content: bicarbonates, chlorides and sulfates of calcium, magnesium, potassium and sodium	6,2
8	Total phosphorus, mg/dm^3	<0,025
9	Chemical oxygen demand (COD), mg O_2/dm^3	35680

Thus, it follows from our data that pyrolysis water may have commercial value as a liquid compound fertilizer concentrate intended for application on different soils to provide mineral nutrition for farm crops. It should be noted that the product composition is similar to liquid manure. Distinguished by the absence of pathogenic microflora destroyed by high-temperature pyrolysis, the final product retains most important nutrients (nitrogen, potassium, phosphorus, etc.). The liquid manure fraction has to pass according to sanitary regulations a detoxification treatment, the solid one also provides for a long-term composting process (ca 12 months). It supposes that the producers must pay for adverse impact on the environment.

As shown by the data obtained in our study, the carbon residue left after manure treatment contains 64.81 % of carbon, has a high calorific efficiency comparable to that of brown coal and wood fuel, and can be used as a fuel cell in solid-fuel boilers for heat generation or gasification with generator gases mostly comprised of hydrogen and carbon monoxide.

Besides, the solid residue contains some useful substances (iron, phosphorus, potassium, titanium, magnesium, manganese, calcium, silicone and sodium) making it appropriate for use as a fertilizer (similar to wood ash) to enhance soil productivity and provide crops with mineral nutrients.

Excessive heat produced by the operating plant can be used to meet technological and utility requirements of the customer.

The manure pyrolysis plant can be implemented in two versions: stationary and portable (with a high degree of prefabrication and a capability of rapid capacity buildup). It only needs a site with paved even surface for installation.

Specific capital investments per 1.0 kW of plant capacity vary in a range of 1200-1900 euros including installation and commissioning. The payback period is within 3 years.

COMPARATIVE ANALYSIS OF MANURE PROCESSING METHODS

Per 1 ton of fresh manure

Fresh bovine manure pyrolysis at biogas plants (PULSAR)	Fresh bovine manure processing at biogas plants (mesophilic process)
Processing cycle	
1 hour	10 days (average value)
Gas production, m^3	
80,83	40-50
Process maintenance gas consumption, %	
15-20	до 20
Biomass decomposition level,%	
100	40
Time between first equipment start-up and gas product output	
2 hours	30-50 days
Gas output per 1 kg dry matter, m^3	
0,28	0,25–0,34
Gas product combustion value, MJ/m^3	
43,2	22,0
Gas consumption per 1 kW/h of electric power, m^3	
0,3	0,36–0,38

Biological hazard from solid production wastes	
	Residue is not disinfected, high helminth content
Slurry acidity and nutrient content requirements	
None	Monitoring of optimum acidity and sufficient nutrient/microelement content is required
Feedstock requirements	
None	Careful selection of slurries to ensure required biogas output
Temperature requirements	
Broad temperature range, + 600 °C and more	Narrow temperature range, + 10 °C
Potable water by-production from the ambient air, t/day	
Up to 35 t	Impossible
Design and construction works	
Not required (portable version)	Required (permanent structures)
Specific capital investments per 1.0 kW of plant capacity, euros	
1200–1900 (including installation and commissioning)	3000–5000 (net of installation and commissioning)

Based on our pilot engineering and R&D works, we may conclude that our technology surpasses the biogas method in all aspects listed below:

- Pyrolysis process does not require much time and significant power consumption;
- Production plant implementation does not require capital structures and design works;
- The plant is completely self-sustained. Any excessive heat and electric power is fed to the customer;
- Pyrolysis plant operation does not involve air pollution by stack effluents. The equipment design does not include a smokestack because the reactor is heated by electric energy from the high-BTU pyrolysis gas product;

- Our method of manure processing is waste-free. Useful products include: gas, solid fuel, liquid mineral fertilizer concentrate and electric power, and potable water condensed from the ambient air;
- 100% purification of solid residue and liquid fertilizer from pathogenic microflora;
- Equipment installation and startup period within 7 days.

Considering that manure is a permanently renewable feedstock source, we are carrying on research in other manure types (swine, horse, sheep, chicken).

It deserves special note that our R&D engineering team is also engaged in the development of **green*** hydrogen, carbon and nanocarbon technologies.

** Hydrogen produced by this method falls under section Renewable Hydrogen according to Clean Hydrogen Production Strategy of **Clean Hydrogen Alliance**.*

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